Appling ETFE Material as Pneumatic Modular Cushions in Workspace's Fascade For Saving Energy

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Abstract

According to all current studies, global warming and climate change are causing disasters for humanity. As a technique to improve natural light effectiveness in deep office spaces, integrating daylighting systems within building skin has become a lot of attention. However, maintaining the stability and uniformity of daylight distribution throughout the day inside a building remains difficult. Consideration of energy efficiency in buildings and sustainability factors will result in large energy savings, environmental savings, and reduction of greenhouse gas emissions. ETFE foil has been increasingly employed as a building material for building envelopes over the past decades to generate green buildings. The research focuses on a new shading method for ETFE-membrane pneumatic modular cushions. The risk of overheating and glare effect in the summer is particularly considerable due to the high visual transmission of an ETFE foil (one layer transparent ETFE foil 92% @ 200m). As a result, a novel angle-selective shading system filters direct sunlight while allowing diffuse sunlight to enter the building. This solution, in particular, implies a reduction in cooling energy demands, which should improve thermal, daylighting and saving energy in the workspace. the researcher applies ETFE pneumatic modular cushions on the (DAR AL-Handasah) office building at smart-village as a case study to measure the effect of the cushions after and before in saving energy. A parametric design approach will facilitate a multistep comparison study to identify the proper design for the system.

Keyword's

ETFE fabric membrane, daylighting quality, pneumatic structure, adaptive façade, energy saving, workspace.

1. Introduction

A building envelope is a physical barrier between the external environment and the internal conditioned space, keeping the residents comfortable. A building envelope consists of fenestration (doors and windows), roofs, walls, and insulations. Since a building envelope separates the unconditioned exterior environment from the conditioned interior space, it is one of the key factors that impact building energy consumption. Building envelopes of energy-efficient buildings are not simply barriers between interior and exterior; they are building systems that create comfortable spaces

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by actively responding to the building's external environment and substantially reducing the buildings' energy consumption.[1]
ETFE does not become brittle or yellowed because it absorbs a minimum amount of UV radiation and has a self-cleaning effect [2] These properties allow for long-lasting applications. ETFE foils can be printed (fritting) with different printing patterns (e.g. points) and colours (optimal colours have a high reflection capacity). Furthermore, tinted ETFE material can be used in several colours. Thereby the optical properties (transmittance [τ], reflectance [ρ] and absorption [α] coefficients) can be controlled by the pigmentation grades and printing patterns.
Because of the lower thermal transmission coefficients (U-value), transparent membrane constructions with a U-value of about 2.1 W/m2K (@ three-layer construction) [2] will always act as a heat sink compared to opaque exterior walls or roofs with a U-value of about 0.28 / 0.20 W/m2K [3]. As a result of the reduced solar gains, the need for heating energy will rise. However, the strong visible transmission of membrane construction results in the high utilisation of incoming daylight and a reduction in artificial illumination inside the building. Otherwise, without adequate sun protection, the risk of overheating due to increasing solar gains in summer is very considerable. Typical materials for transparent membrane constructions are ethylene-tetra-fluoro-ethylene (ETFE). A relatively uniform daylight range of 500–2000 lux was intended to be kept over the task plans in the model of an 8 m deep office.
The paper (N. Elakkad and W. S. E. Ismaeel, 'Coupling performance-prescriptive based daylighting principles for office buildings: Case study from Egypt', *Ain Shams Eng. J.*, vol. 12, no. 3, pp. 3263–3273, Sep. 2021, doi: 10.1016/j.asej.2020.09.030) reviews guidelines and assessment methods for daylight performance for office buildings in Egypt to propose a Unified design guideline (UDG). The UDG was tested for two local case studies using building simulation; a non-LEED building complying with a set of limited guiding principles of the local code, and a LEEDcertified building with an additional set of guidelines, and compliance path using building simulation. The comparison showed that the integration of both prescriptive and performance-based guidelines and measurement criteria is necessary to develop the UDG tailored to address the particular requirements of office buildings in terms of daylight performance in similar climates, but this research didn't make the energy efficiency impact on the modified building, also it didn't use any new shading techniques to avoid glare, high temperature and daylighting uniformity.
Also the paper (J.-F. Flor, Y. Wu, P. Beccarelli, and J. Chilton, 'Dynamic environmental control mechanisms for pneumatic foil constructions', *E3S Web Conf.*, vol. 22, p. 00048, 2017, doi: 10.1051/e3sconf/20172200048.) A parametric study was carried out on a switchable ethylene-tetrafluoroethylene (ETFE) foil cushion to investigate the optical performance of an adaptive building envelope and its impact on building energy performance regarding heating, cooling and lighting, but the study only in printed ETFE

material with air gas pressurized on the typical shape of cushions, there are no variant parameters in the study.

This research focuses on the relationship between using fabric ETFE pneumatic modular cushions on the outer building fascade and the energy consumption during the four seasons (at 9.00 am to 5 pm) on the 21st of June (summer solstice) worst case, with a 100% state of the pressure gas in the cushions.

2. Research problem

Saving energy and achieving optimal daylighting distribution through traditional shading systems such as wood panel curtains, dynamic aluminium louvres, or double glass with isolated gas did not achieve the optimum level of daylighting or energy consumption; however, using a pneumatic modular façade system with ETFE membrane materials injected with Argon gas could improve indoor daylighting in the workspace.

3. Research Aims

The study aims to analyse and use the ETFE membrane material injected with Argon gas in cushions put on the workspace fascade to make the relation between ETFE pneumatic system and saving energy and this will achieve by:

- Define the role of the pneumatic modular system in enhancing the daylight in the workspace
- Illustrating the importance of using ETFE membrane materials in outer building.
- Prove that a pneumatic facade has a vital role in promoting daylighting inner the workspace.
- Compare the use of default shade outer the skin of the business building and the pneumatic modular cushions during the year and point in time.
- Explore the technical usage of a pneumatic modular fascade instead of any shading system.
- Extract the analysis from a real case study (DAR AL-Handasah) to show the best results and measurement metrics in daylighting and energy efficiency.

4. Research Methodology

For attaining the research aims, the methodology was divided into two parts; ***First,*** investigate the pneumatic modular façade and the different types and techniques. And explore the specification of the best material using the pneumatic ETFE and choose the type of techniques used for measuring. ***Second,*** analyze the daylighting with an annual, point-in-time simulation by parametric approach and energy simulation using rhino&grasshopper for modelling and climate studio for climate simulation of the case study (DAR AL-Handasah). ***Finally***, compare the results of the case studies after and before using the pneumatic modular system in the outer fascade.

4.1 The Pneumatic Adaptive Façade

4.2.1 ETFE pneumatic modular cushions material of the outer skin

The envelope will be modular units of cushions with shapes proportional to the height of the façade and will consist of two or quad-layer ETFE material filled with Argon gas and will work as an external shade that protects the curtain wall glass facades of the administrative space, and all the inflated cushions will work as a single element that will be controlled by an external sensor that receives climatic readings and works on the immediate response changing the situation as a reaction to the changes of the surrounding environment in maintaining natural lighting inside the space and reducing the high temperature, saving energy and also the pneumatic cushions act as a (Daylight Reflector element) reflecting sunlight on the ceiling of the space which helps to increase the illuminance in the depth of the workspace called (Daylight penetration depth)

Figure 1 Double-skin façades with ETFE A) Unilever Headquarters in Hamburg, with single-layer clear ETFE; B) Tic-Media Building in Barcelona with double-layer ETFE cushion in south-west façade, C) Canary Wharf Crossrail Station in London with fritted double-layer ETFE cushion Source :(Pictures by J.-F. Flor, 2016/2017).

4.2.2 Select the type of ETFE cushions mechanism on fascade

As we see in (figure 2a) the ETFE cushions are installed modular in the hinged structure on the slab and there are three states on the pneumatic cushions, clear ETFE which make the lighting enter the space with full daylight, fritted ETFE which makes semi-opaque transparent window that the layer of ETFE in the middle of two main layers which makes 50% of lighting inter the workspace, switchable ETFE that it’s the extra shading device active and the lighting enter the space 15-25% according to the workspace required.

(figure 2b) describe an example of a workspace containing the height of the work plan and how the ETFE cushions affect the distribution of daylighting in the space.

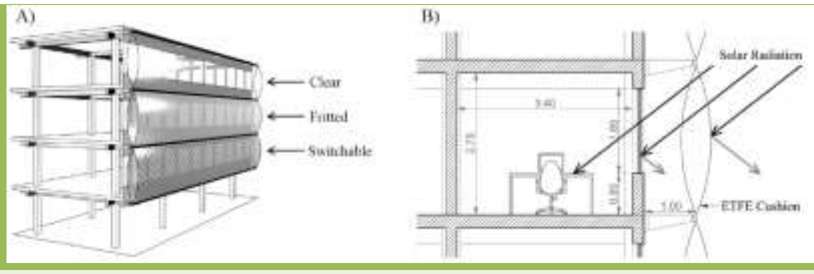


Figure 2 A) Visualization of a building structure with a double-skin façade with different ETFE foil types. B) Section of a typical single-unit office room with an ETFE double-skin façade and incident solar radiation.

4.2 Elements of energy efficiency

4.2.1 Increasing thermal resistance of the building envelope

Increasing the thickness of the insulating material is the simplest way to increase the thermal resistance of a facade. The method was very popular, especially in Northern Europe. This is evident from the fact that the thickness of insulation in buildings has increased since the early 1970s, almost doubling in Northern Europe[4]. Increasing the thickness of insulation results in increased cost. Walls with thermal insulation also have a higher possibility of surface condensation when the relative humidity of ambient air is greater than 80%, provided the convective and radiative heat transfer coefficients of the exterior wall are small [5]. This is undesirable because it promotes microbial growth raising health issues, as well as reducing the life of the building envelope. [6]

4.2.2 Climate-specific design of energy-efficient envelopes

Other methods of attaining high energy efficiency in building envelopes and thermal comfort levels take into account the local climate. Strategies that work in dry and cold climates may not necessarily work in humid and hot regions. Researchers have developed design strategies for different locations. One such strategy [1] is summarized in (Table 1). [6]

Climate type	Design strategies for energy-efficient facades
Heating-dominated	- The building envelope receives solar heating. - Walls can be used as thermal masses for thermal storage. - Better insulation to minimize thermal losses. - Natural daylight is used. Facades have increased glazing areas to allow for natural light; light shelves that redirect light into interior spaces are used.
Cooling-dominated	- Appropriate shading techniques can be employed to protect from direct solar gain. - Use insulation to reduce solar heat gain. - Design to facilitate natural ventilation (wing walls).

	- Natural daylight should be used in such a way that solar heat gain is minimized.
Mixed climates	- Use shading devices to protect the facade from direct solar radiation during warm days. - Use the passive solar design for heating during cold seasons. - Use natural daylight and increased glazed areas of walls with shading devices.

Table 1 Climate-specific design of energy-efficient envelopes.
Source: [6]

4.2.3 Solar and orientation factors and shading coefficient

The solar factor (SF) is the average hourly rate at which solar radiation incident upon the vertical surface; it is expressed in W/m2. Both diffuse and direct radiation is included in the solar factor. The vertical radiation is averaged over the period 7:30 a.m. to 5.30 p.m. The average solar factor over eight orientations is equal to 270 W/m2.The solar factor for Cairo, Alexandria and Aswan were calculated from a computer program developed especially for this study, see (Table 2).

Orientation	SFN	SFNE	SFE	SFSE	SFS	SFSW	SFW	SFNW	SFRF
Cairo	113.5	194.9	330.3	408.1	415.0	408.1	330.1	194.9	629.3
Alexandria	111.4	191.0	326.7	409.1	419.8	409.1	326.8	191.0	620.0
Aswan	125.7	259.9	345.0	395.3	379.8	395.3	345.0	259.9	669.8

Table 2 Solar Factors (SF, W/m2) for Egypt Source: [7]

The Window Orientation Factors (OF) were derived by normalizing the Maximum Solar Heat Gain Factors for June at Cairo, Alexandria and Aswan Latitude, see (Table 3), (BECP 1990).

Orientation	OFN	OFNE	OFE	OFSE	OFS	OFSW	OFW	OFNW
Cairo	0.65	1.07	1.27	1.04	0.60	1.04	1.27	1.07
Alexandria	0.63	1.05	1.27	1.05	0.63	1.05	1.27	1.05
Aswan	0.77	1.15	1.28	0.94	0.48	0.94	1.28	1.15

Table 3 Solar Factors (SF, W/m2) for Egypt
Source: [7]

The shading coefficient (SC) of the fenestration system is defined as a ratio of solar heat gain through the fenestration system having the combination of glazing and shading device to the solar heat gain through un-shaded 3mm clear glass., see (Table 4) for Glass Types Characteristics, (ASHRAE 1997).

Name	U	SC	SHGC	TVIS
Single Glazing_Clear	6.17	0.95	0.81	0.88
Single Glazing_Blue	6.17	0.71	0.61	0.57
Single Glazing_Grey	6.17	0.69	0.59	0.43

Single Reflective (Class A) 1 Clear High Emissivity	5.41	0.36	0.31	0.20
Single Reflective (A) Tint Medium Emissivity	5.11	0.29	0.25	0.09
Double Glazing BronzeTint	2.74	0.57	0.49	0.47
Double Glazing GreenTint	2.74	0.57	0.49	0.66
Double Glazing Tint Low Emissivity	1.78	0.37	0.28	0.44
Double Glazing, Reflective (A) Clear Medium Emissivity (IG)2	2.35	0.20	0.17	0.13
Double Glazing, Reflective (A)Tint, Medium Emissivity (IG)	2.35	0.18	0.15	0.08

(Table 4) Glass Types Characteristics – 1 Class A, the inner surface of the exposed sheet - 2 Insulated Glass
Source: [7]

4.3 Simulation methodology

4.5.1 Basic settings for the simulation process (pre-simulation)

In which the Rhino program and the simulation files used in the study are prepared from the Grasshopper program so that they pave the way for obtaining sound results, and in which the plugins (Climate studio environmental design tools – weaver bird plugin for pattern generator - Kangaroo plugin for pneumatic cushions and structure form) used in the simulation process are determined and the variables and constants in the model are determined, as well as variables related to natural lighting (Radiance setting) As well as the requirements that determine the simulation process (Location, Date, Time) In addition to the variables of the case study in the research, which is everything related to the pneumatic fascade of basic variables, which are as follows

Pneumatic fascade variants that control the simulation process

1. Cushion size
2. Cushion shape
3. Amount of gas to inflate the cushion
4. The number of layers of ETFE in the cushion
5. Annual - Point in time (peak time)
6. Static and dynamic shading
7. The direction of the simulation space

Noting that these variables enter as an influential factor in some stages or are fixed in other stages depending on the goal of each stage and according to the need for it or not. (adapted by the researcher)

4.5.2 First stage: Annual Dynamic Simulation

At this stage, the simulation model is tested throughout the Annual Simulation and is subject to a set of dynamic metrics (SDA, ASE, illuminance) This test is done on all pneumatic fascade.

This stage aims to determine the measurements and ratios that achieve the best level of lighting that enters the workspace through pneumatic facades throughout the year, in addition to the lowest percentage of exposure to Direct Sunlight, After the results of the simulation appear, the results are evaluated according to a group of rating systems As Leed v4.0 option1.0 And another set of codes such as IES to determine percentages and values. that achieves the best level of illuminance.

In the next stage, these values are used in the instantaneous simulation process as fixed values during the test and another set of independent variables is developed. (adapted by the researcher)

4.5.3 Second stage: Point In time simulation

Tests are specified on the simulation model in the case of Point In Time Simulation, and this test is conducted over eight hours during the day from 9 am to 5 pm, on three critical days throughout the year, which are:

21 March – 21 June – 21 December

This test is carried out in two forms of case study model It is as follows

- Base case model

It is the original case of the space without the pneumatic fascade and it is with glass coverage only without any shadow elements, only the same measurements of the opening, which represents 90% of the wall area and the glass casing only without any shadow elements.

- Best annual case model

It is the case that contains the entire pneumatic facade and works on the reaction of solar radiation throughout the daylight hours and responds to the variables of the surrounding climate. (adapted by the researcher)

4.5.4 Third stage: Simulation results

The results of the previous cases are recorded to compare those cases to achieve the aforementioned indirect goals, which are:

- The use of a pneumatic fascade with studied proportions supports obtaining the best levels of illuminance from those cases in which the fascade is covered only with glass, even if it is thermally insulated.
- Reaching the specifications of the best cases The study that achieves the best levels of desired lighting inside the workspace throughout the day, as a step in the stages of entering these results into the special program (rhino&grasshopper) responsible for controlling the behaviour of the outer fascade of the building throughout the day and year.
- Thus, through these steps, the overall goal has been achieved, which is to develop a methodology for selecting and studying the features of the pneumatic fascade to obtain the best levels of illuminance inside the administrative spaces, as well as to save energy by reaching thermal comfort inside the spaces. (adapted by the researcher)

4.4 Simulation conditions (constraints and variables)

Include all the parameters that affect the variables of the simulation model as follows

4.4.1 Location, date, time condition

The site selection factor is very influential in the simulation process, and areas will be selected in which the largest percentage of administrative and government buildings will be built at the level of the Republic, such as (the new administrative capital - Smart Village), in addition to being one of the areas with a hot climate, which is the prevailing climate in most regions of the Middle East.

The climate file for the region is uploaded to the program climate studio and dealt through it to reach accurate climate results

As for time, the days of the solstice between the seasons are critical times that illustrate the climatic features of the seasons, and therefore they were chosen as appropriate times for the application of the simulation model, which are as follows:

- 21 June is a critical time for the summer solstice.
- 21 March - September is a critical time for the solstice of the temperate seasons (Equinox).
- 21 December is a critical time for the winter solstice.

As for the choice of the building, it will be applied to the cases of buildings already existing and working and will be studied at the level of the role so that the effect of pneumatic facades is clear in the simulation and its impact on improving natural lighting and maintaining temperatures inside the workspace.
The presence of adjacent buildings was also ignored and not included as simulation elements to help speed up the simulation process.

4.4.2 Research variables and constants

There are a set of variables and constants that directly affect the performance of natural lighting within the space, and a table as follows discusses the constants and the variables in the applied case study model :

Type	Constraints	Type	Variables
Pneumatic Material	We choose the white colour of ETFE material to make more reduce heat transmission and glare control on the inner workspace.	Size of pneumatic cushions	The size of the pneumatic cushions hinged structure on the slab that makes up the casing concerning the inner workspace.
Location of penumatic fascade on model	The applied pneumatic facade will be on the south only that the solar radiation is direct and the highest glare than the other facades	Amount of air in pneumatic cushions (10-50-100%)	The amount of gas pressure used to blow the cushions on the pneumatic façade according to the climate conditions for adapting.
The date of the simulation	We will simulate the model in the worst case of Days of the Solar Solstice 21 from June, march and December	Layers of pneumatic cushions	The number of pneumatic ETFE cushion layers that affect extra shading and energy consumption of heat transmission.
The time of the simulation	The hours of work will be 8 h to simulate in it, from 9 am – 5 pm	Amount of daylighting on the working space	Depend on the wwr that allows the daylight to enter the workspace without glare
Geometry model	The geometry model space dimension as one open workspace	Illuminance level	acceptable illuminance for normal office work should be between 500 and 1000 lux
Workspace material	The materials of the space finish as floor, wall and ceiling to see	Thermal resistance	Summer conditions: optimum temperature of 24.5°C with an acceptable range of 23-26°C

	the effect of diffuse reflectance		Winter conditions: optimum temperature of 22°C with an acceptable range of 20-23.5°C (by CSA Z412-17 Office Ergonomics)
Amount of daylighting required	The amount of lighting entire the workspace that 300lux as the minimum req.		

Table 5 shows the constraints and variables in the research case model to apply to it. Source: adapted by the researcher

The following is a presentation of the table of variables according to the research study, which will be the simulation through it the Grasshopper and climate studio program:

Category		Name	Type
Geometry model space	**Main space**	Orientation	Constant
		Depth	Constant
		Width	Constant
		Height	Constant
		Type and Reflectance	
		Floor	Constant
		Wall	Constant
		Celling	Constant
Static shading device		Permeability	Constant
		Length	Constant
		Width	Constant
Dynamic pneumatic shading device		Material	Constant
		Colour (RGB)	Constant
		Specularity	Variable
		Roughness	Variable
		Transmission	Variable
		Transmitted	Variable
		Air amount in cushions	Variable
		Number of layers	Variable
		Window-to-wall ratio (WWR)	Constant
Glazing curtain wall		Number of layers	Constant
		Properties	Constant
		Window-to-wall ratio (WWR)	Constant

Table 6 Clarifies the basic classifications of the variables and constants of the research study Source: adapted by the researcher

5. (DAR AL-Handasah) a case study using a pneumatic modular system and the criteria of saving energy using some techniques

Location	6th october city, smart village, Egypt
Main usage	Hybrid programme: offices + workshops
Total Floor Area	4770 [m²]
Total Building Surface	41800 [m²]
Adaptive Facade Surface	6300 [m²]
Adaptable properties	sun protection
Architect	Perkins + Will
System	Double glazing
Year of construction	2015-09

Figure 3 Dar Al-Handasah main fascade Source:https://dar.com/CMS/Content/ResizedImages/1287x10000xi/160303101834007~DAR09122_01D_N10.jpg

we will apply the previous methodology with the constant and variables to measure daylighting and thermal outer fascade of the actual model built in Rhino and Grasshopper with two cases: the basic model (containing actual parameters of the building) and modified pneumatic fascade model (containing the pneumatic double fascade skin) and use the Annual Dynamic Metric simulation and Static Metric simulation (Real-time simulation) to measure the difference of daylighting in the workspace.

The researcher uses the simulation in climate studio Version 1.9 with an academic license in Rhino and using the Leed 4.0 version option 1 described here, simulates daylight availability throughout the entire year, while Option 2 simulates daylight availability at two specific moments in time. Option 1 yields a more complete description of the daylighting performance, offers more potential points under the USGBC's rating system and is the recommended compliance pathway for the LEED Daylight Credit, the parameters with Grasshopper to measure the daylighting elements such as (ASE – SDA – Glare – Illuminance – sun radiation on the fascade – site analysis) in the two cases model and after that, we make comparison charts to prove the hypothesis that pneumatic fascade make better workspace daylighting and will measure in the best case the energy thermal between the inner and outer fascade to prove the energy efficiency of the ETFE pneumatic membrane properties.

The steps of simulation will make in three stages – first Data Analysis & Tools then View and analyze lighting and energy simulation data and results after that Comparative study of research results finally The most important results of the analytical study

- Data Analysis & Tools
- View and analyze lighting simulation data and results
- View and analyze energy simulation data and results with the best case
- Comparative study of research results
- The most important results of the analytical study

The stages of the simulation in applied case studies (Dar Al-Handasah):

1- Annual simulation (climate studio) with Basecase model according to building design code (without shades) and Basecase model(with default shades and finally Basecase model with pneumatic ETFE cushions.

2- Point-in-time simulation

2-1 base-case simulation – with standard shading.

2-2 dynamic case simulation – with modular pneumatic ETFE skin with different amounts of gas in cushions.

2-3 After that temperature simulation in the best case with the best pneumatic ETFE skin and with the best shape of cushions.

3- The energy simulation of five zones in different directions.

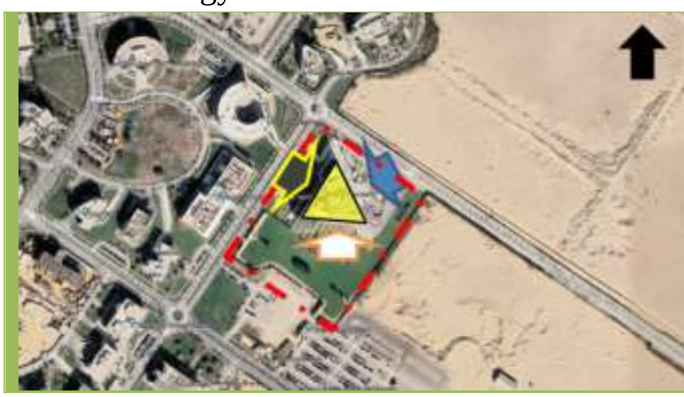


Figure 4 the layout of the building shows the urban context of a smart village and there is no shading building in the dar alhandasa main case study, The three facades which will apply the adaptive systems (pneumatic modular system) are the North, South and Southeast facades, which are the two that have higher sunlight exposure (around 6000 [Wh] per [m²] facade in summer).
Source (Googlemaps)

5.1 Daylighting analysis study

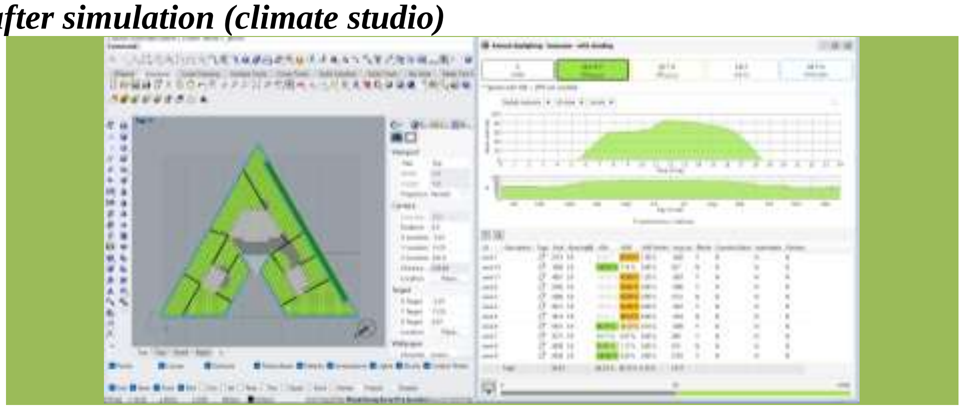
5.1.1 Annual simulation-Basecase model-with fixed shading

Category		Name	Type
Geometry model space	Main space	Orientation	North, South and Southeast facades
		Depth	85 m
		Width	102 m
		Height	3.40 m
		Type and Reflectance	
		Floor	Generic floor type of 20% reflectivity
		Wall	Generic interior wall of 50% reflectivity

	Celling	Generic ceiling type of 70% reflectivity
Static shading device	Permeability	sheer weave 2410 performance 3.7%
	Length	3 m
	Width	Along the curtain wall glazing
Dynamic pneumatic shading device	Material	No pneumatic cushions
	Colour (RGB)	-
	Specularity	-
	Roughness	-
	Transmission	-
	Transmitted	-
	Air amount in cushions	-
	Number of layers	-
	Window-to-wall ratio (WWR)	-
Glazing curtain wall	Number of layers	Sungate 400 (2) – clear (Argon)
	Properties	**Sungate 400 (2) - Clear (Argon)** U-Value[W/(m²·K)] = 1.53 SHGC = 0.596 TVIS = 0.754 Embodied Energy[MJ/m²] = 431.25 Embodied Carbon[kgCO2/m²] = 26.162 **Layers: (Outside - Inside)** 1 - Sungate 400 on Clear 6mm - Flipped 5.7 [mm] 2 - Argon - EN673 127 [mm] 3 - Clear Float Glass Clear 5.8 [mm]
	Window-to-wall ratio (WWR)	Curtain wall

Table 7 Clarifies the basic classifications of the variables and constants of the research study – the time frame of the study is 9 am-5 pm with DST Source: adapted by the researcher

Results after simulation (climate studio)



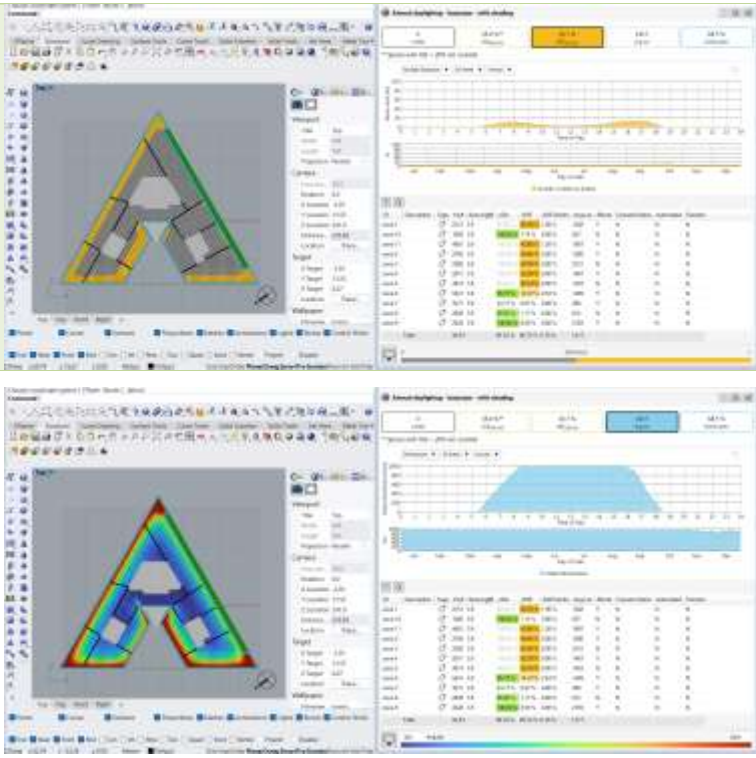


Table 8 the annual daylighting results according to the presetting of the plane in the climate studio show that:
Daylight Autonomy (SDA 36.4%)
Sunlight Exposer (ASE 26.7%)
Illuminance (1417 lux)
All curtain walls have blinds (sheerweave 2410 performance 3.7%)
Leed 4.0 option 1.0 credit 0 **Source:** adapted by the researcher

5.1.2 Annual simulation-Basecase model-with pneumatic ETFE cushions

To apply pneumatic ETFE cushions we will use (kangaroo plugins) to generate the pneuma gas in the cushions according to the percentage volume, we choose the three geometric shapes of cushions and measure the daylighting metrics, choose the type of pneumatic system (F- Double layer with injected gas)

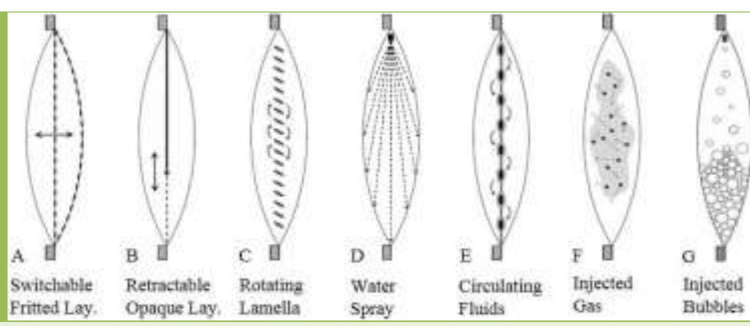
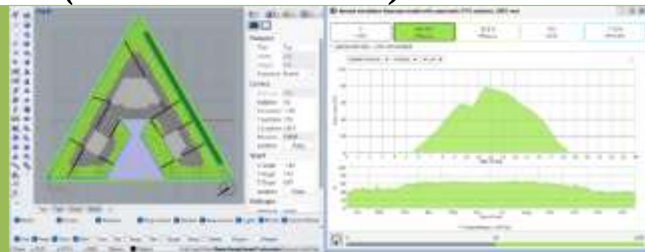
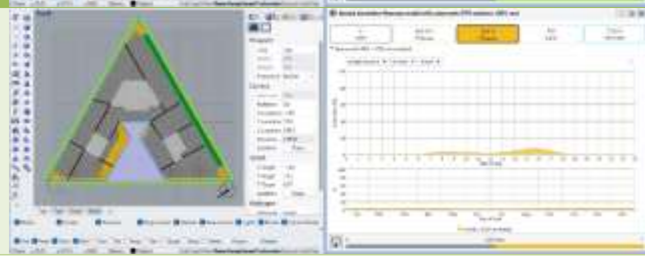


Figure 5 Environmental control mechanisms for multilayer ETFE constructions (we choose the injected gas system) Source:**[8]**

Results after simulation(ETFE cushions 100%)





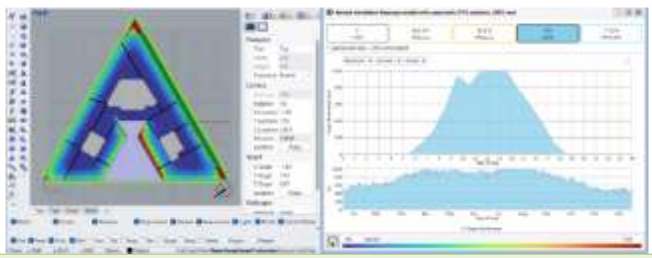


Table 9 the annual daylighting results according to the presetting of the plane in the climate studio show that:
Daylight Autonomy (SDA 36.9%)
Sunlight Exposer (ASE 15.8%)
Illuminance (765 lux)
Blinds open (77.8%)
All curtain wall have blinds (sheerweave 2410 performance 3.7%)
Leed 4.0 option 1.0 credit 0 Source: adapted by the researcher

5.1.3 Point-in-time simulation

The researcher made the simulation on 21 June is a critical time for the summer solstice.

Base-case simulation – with standard shading (21 March)

Category		Name	Type
Geometry model space	Main space	Orientation	North, South and Southeast facades
		Depth	85 m
		Width	102 m
		Height	3.40 m
		Type and Reflectance	
		Floor	Generic floor type of 20% reflectivity
		Wall	Generic interior wall of 50% reflectivity

	Celling	Generic ceiling type of 70% reflectivity
Static shading device	Permeability	No blinds
	Length	-
	Width	-
Dynamic pneumatic shading device	Material	No pneumatic cushions
	Colour (RGB)	-
	Specularity	-
	Roughness	-
	Transmission	-
	Transmitted	-
	Air amount in cushions	-
	Number of layers	-
	Window-to-wall ratio (WWR)	-
Glazing curtain wall	Number of layers	Sungate 400 (2) – clear (Argon)
	Properties	**Sungate 400 (2) - Clear (Argon)** U-Value[W/(m²-K)] = 1.53 SHGC = 0.596 TVIS = 0.754 Embodied Energy[MJ/m²] = 431.25 Embodied Carbon[kgCO2/m²] = 26.162 **Layers: (Outside - Inside)** 1 - Sungate 400 on Clear 6mm - Flipped 5.7 [mm] 2 - Argon - EN673 127 [mm] 3 - Clear Float Glass Clear 5.8 [mm]
	Window-to-wall ratio (WWR)	Curtain wall

Table 10 Clarifies the basic classifications of the variables and constants of the research study – the time frame of the study is 9 am-5 pm (8 hours) with DST **Source:** adapted by the researcher

Results after simulation (climate studio)

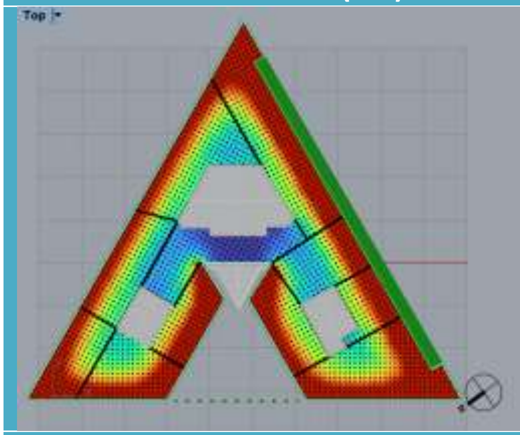
Result sensors(lux)	Time (/1hour)	Mean lux	Median lux
	1 pm (21 March)	4110	2256

Table 11 shows the point-in-time daylighting simulation of the North, South and Southeast facades on 21 March from 9 am-5 pm The working hour occupancy – neglecting the artificial lighting. Source: adapted by the researcher

Dynamic case simulation – with modular pneumatic ETFE cushions (21 June)

To apply pneumatic ETFE cushions we will use (kangaroo plugins) to generate the pneuma gas (Argon) in the cushions according to the percentage volume(10%-50%-100%) and with double cushions (10+100% – 50+100% – 10+50%), we choose the diamond geometric shape of cushions and measure the illuminance (lux) in the workspace floor from 9 am-5 pm

kangaroo plugin grasshopper definition

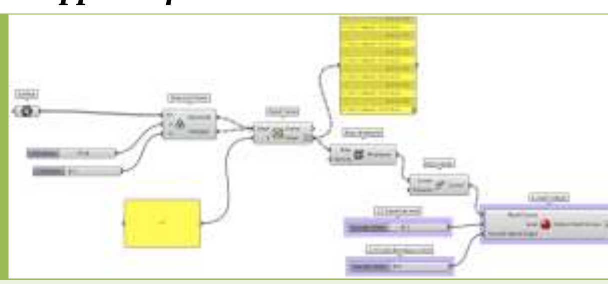


Figure 6 shows the assigned cushion position on the model and created with the Weaverbird plugin to shape the cushion (diamond panels) compatible with the fascade

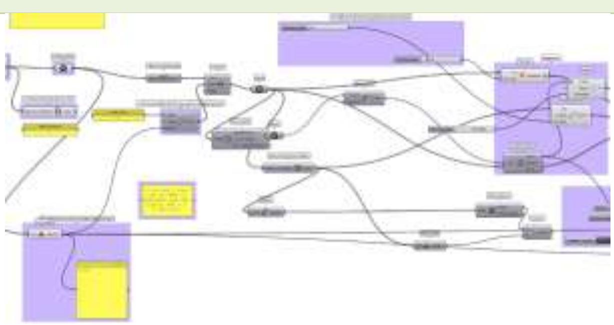


Figure 7 shows settings of the pressure and gas amount (Argon gas) in the cushions to convert in pneumatic fascades for all the North, South and Southeast facades

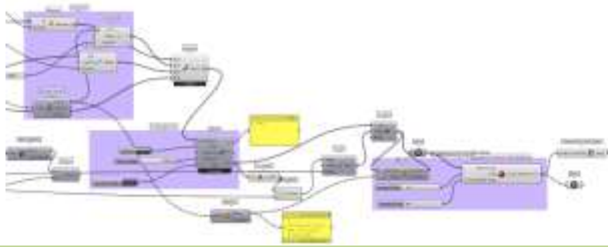


Figure 8 shows the final stage of a pneumatic button to start and fill the gas in the cushions with different pressure strengths and bake the result to apply in the model as a(pneumatic fascade)

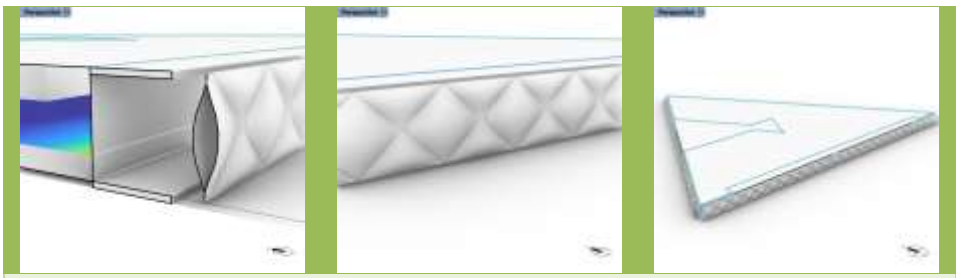


Figure 9 shows the shape of the pneumatic cushions on the outer fascade fill with argon gas 10% and the glazing behind the ETFE cushions, there are two fixed shaded cantilevers 2.80 m in the south fascade as built in the base case.

Figure 10 shows the pattern of diamond shape overlapped to cover all the curtain wall glazing wwr 1:1 on all the building fascade.

Choosing Pattern before simulation

The choosing pattern depends on the shape of the building and the aesthetic methods, we use only in this research the geometric pattern as the edge overlaps on the fascade, the change of the shape of the pattern will not affect the results and it depends on the designer choice shown in(Figure 11)

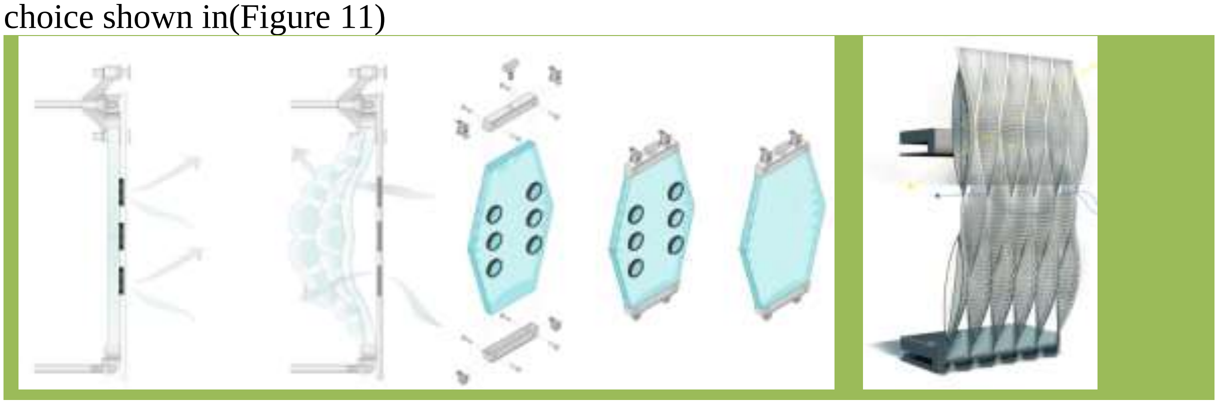


Figure 11 shows the various choice of the pattern pneumatic cushions on the outer fascade.

Category		Name	Type
Geometry model space	**Main space**	Orientation	North, South and Southeast facades
		Depth	85 m
		Width	102 m
		Height	3.40 m
		Type and Reflectance	
		Floor	Generic floor type of 20% reflectivity
		Wall	Generic interior wall of 50% reflectivity
		Celling	Generic ceiling type of 70% reflectivity
Static shading device		Permebility	sheerweave 2410 performance 3.7%
		Length	3 m
		Width	Along the curtain wall glazing
Dynamic pneumatic shading device		Material	ETFE
		Colour (RGB)	0.44
		Specularity	0.29
		Roughness	0.00
		Transmission	0.16
		Transmitted	0.40
		Air amount in cushions	10%-50%-100%
		Number of layers	Double layer
		Window-to-wall ratio (WWR)	1:1
Glazing curtain wall		Number of layers	Sungate 400 (2) – clear (Argon)

	Properties	**Sungate 400 (2) - Clear (Argon)** U-Value[W/(m²·K)] = 1.53 SHGC = 0.596 TVIS = 0.754 Embodied Energy[MJ/m²] = 431.25 Embodied Carbon[kgCO2/m²] = 26.162 **Layers: (Outside - Inside)** 1 - Sungate 400 on Clear 6mm - Flipped 5.7 [mm] 2 - Argon - EN673 127 [mm] 3 - Clear Float Glass Clear 5.8 [mm]
	Window-to-wall ratio (WWR)	Curtain wall

Table 12 Clarifies the basic classifications of the variables and constants of the research study – the time frame of the study is 9 am-5 pm with DST Source: adapted by the researcher

Results after simulation(climate studio)(ETFE cushions 100%)

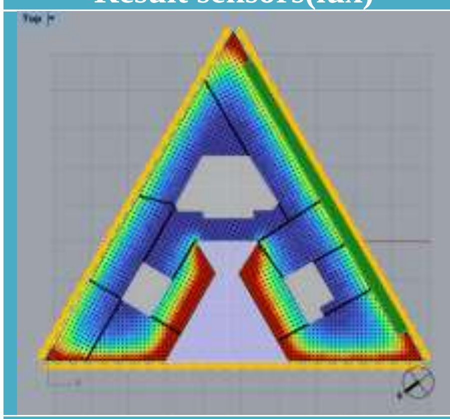
Result sensors(lux)	Time (/1hour)	Mean lux	Median lux
	1 pm (21 June)	1541	857

Table 13 shows the point-in-time daylighting simulation of the North, South and Southeast facades on 21 June from 9 am-5 pm The working hour occupancy – neglects the artificial lighting. **Source:** adapted by the researcher

5.2 Energy Efficiency Study

5.2.1 Adjust The Model For Analysis

First, we divide the floor plane into (5 zones) as workspace in the different fascade directions (Figure 12) The researcher will analyse (zone 1,2,3,4,5) with default shade and the other with pneumatic cushions shade and make compare results. (Figure 13) Choosing material the same as in the previous stage of daylighting analysis to apply in the energy efficiency simulation.

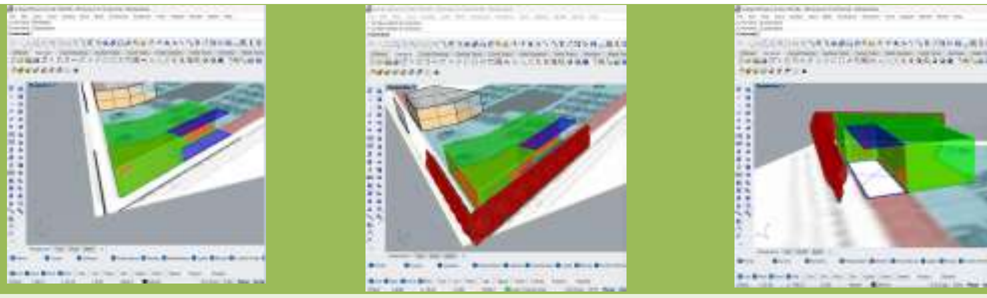


Figure 13 shows the generation of the pneumatic ETFE cushions on the fascade tand analyzes energy for two cases (one for pneumatic and the other for default shading). **Source:** adapted by the researcher

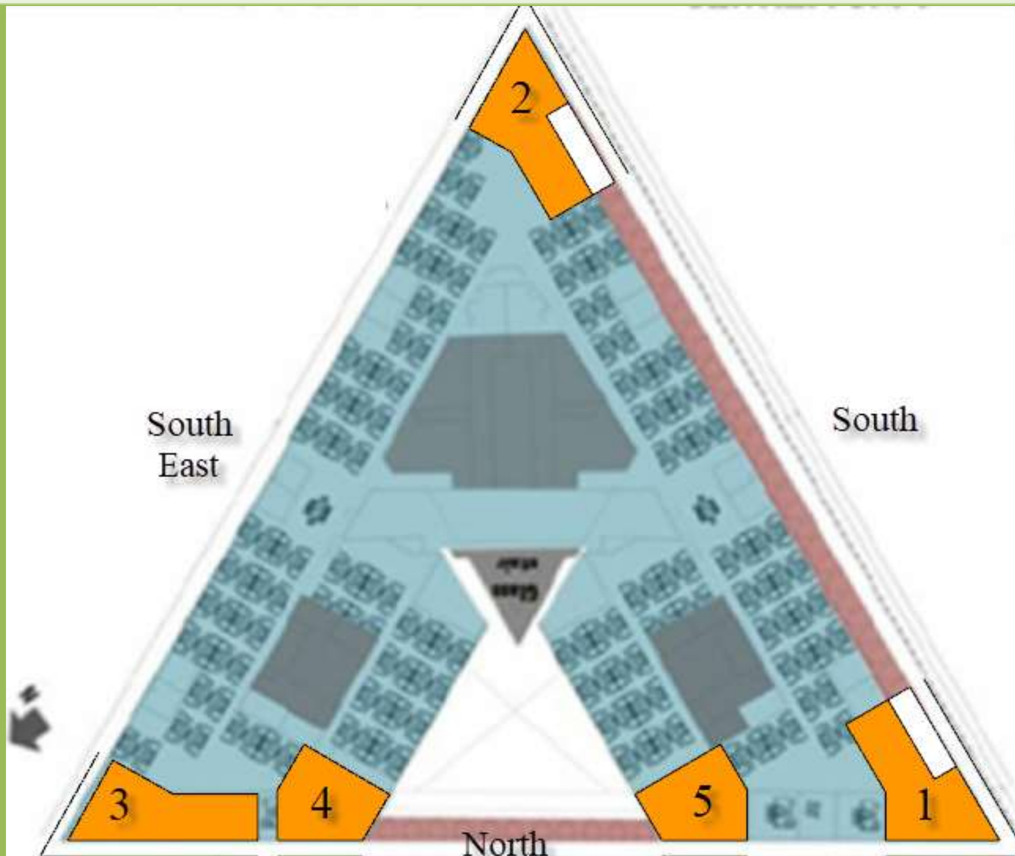
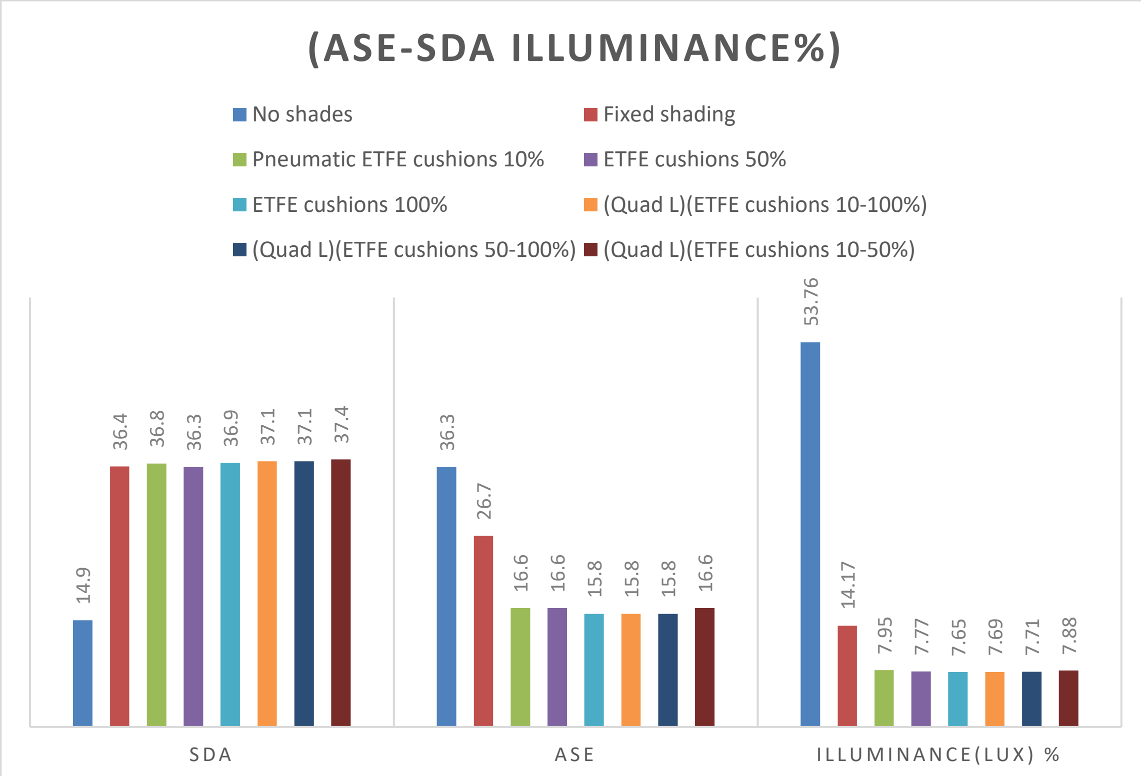


Figure 12 shows the five zones (orange colour) in the 3 directions of the building **Source:** adapted by the researcher

5.3 Results and discussion

- Annual daylighting simulation comparison



sDA: Spatial Daylight Autonomy: Percent of space receiving at least 300 lux for at least 50% of occupied hours.

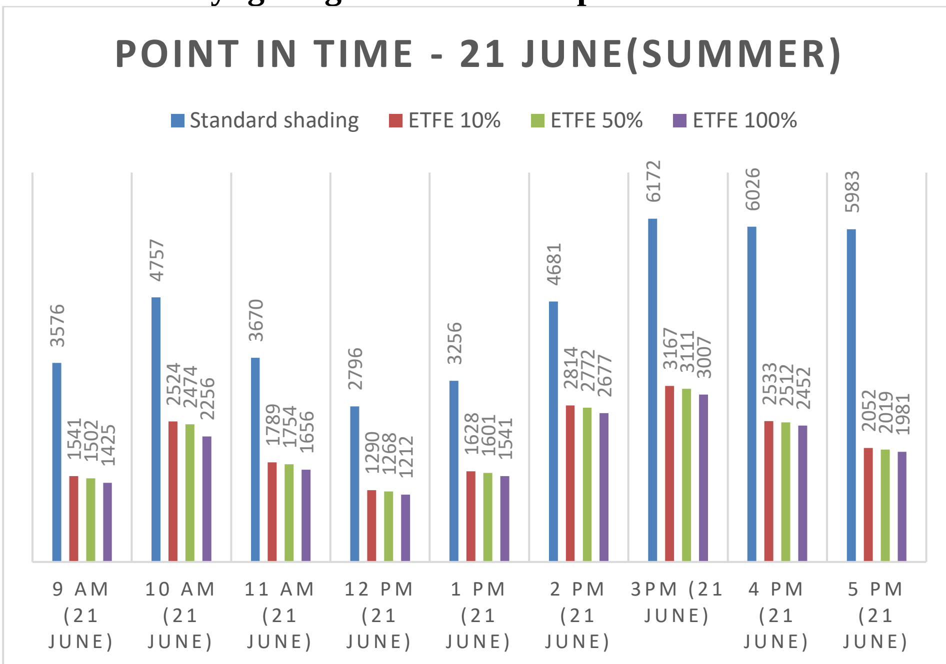
The case of (no shades) causes the low SDA in the workspace and when we put the (pneumatic shading ETFE) material with different states of Argon amount of gas in the cushions SDA raises in the workspace uniformity from (14.9 to 37.4)

ASE: Annual Sunlight Exposure: Percent of space receiving at least 1000 lux direct sun for at least 250 occupied hours.

The case of (no shades) causes the highest sunlight exposure in the workspace and when we put the (pneumatic shading ETFE) material with a different state of Argon amount of gas in the cushions ASE decreases in the workspace uniformity from (36.3 to 15.8)

Avg Lux: Mean work plane illuminance during occupied hours, The case of (no shades) causes the high illuminance in the workspace compared to the (pneumatic shading ETFE) material with different state of Argon amount of gas in the cushions illuminance de decreases in the workspace uniformity from (53.76 to 7.65)

- **Point-in-time daylighting simulation comparison**



Point in time simulation on 21 March, June and December It is noticeable that the value of mean lux in the workspace from 9 am to 5 pm decreases about 50% between the case of standard shading and the case of pneumatic modular fascade with ETFE cushions.

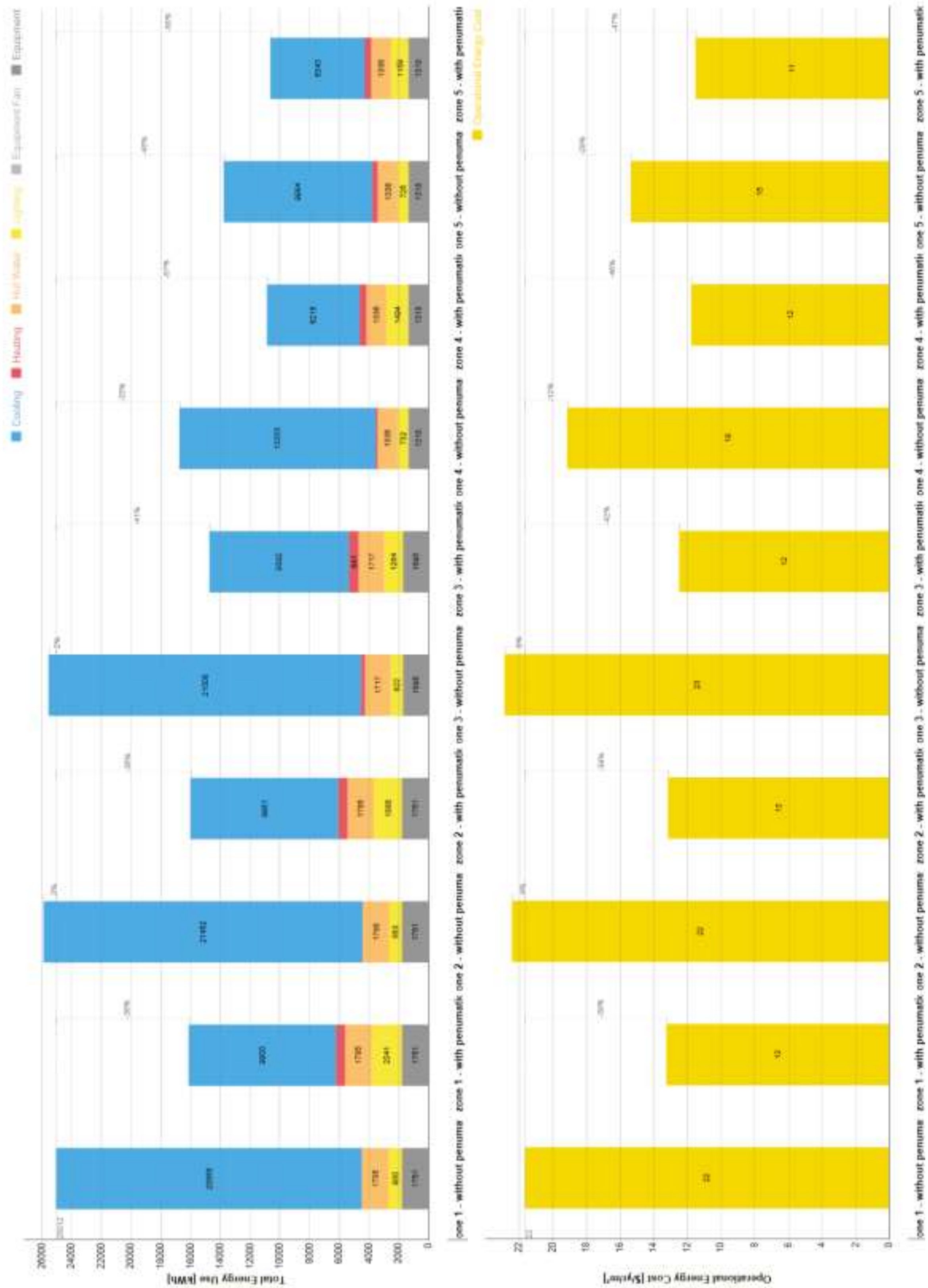
- **Energy Efficiency Comparison**

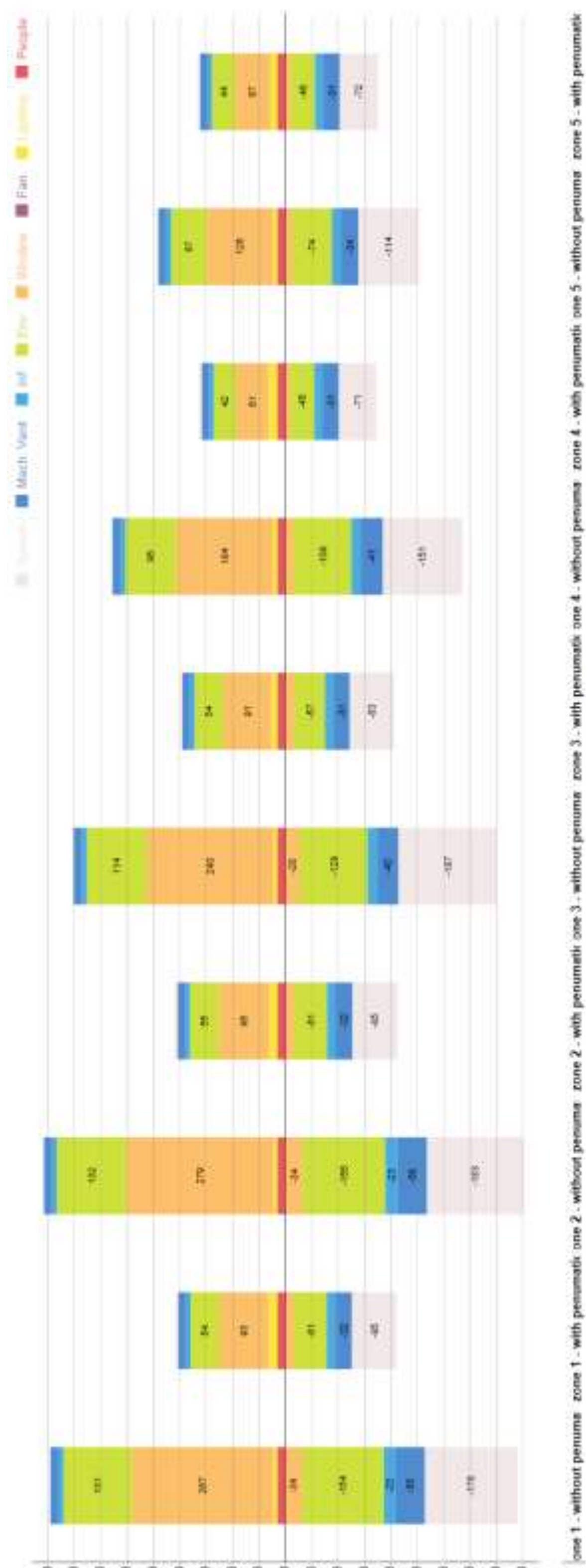
The Energy Efficiency consists of 6 main factors (cooling – heating – hot water – lighting – equipment fan – equipment) the cooling factor in the summer season decreased in Zone 1 (North and South) up to 36%, Zone 2 (South and Southeast) up to 38%, Zone 3 (North and South-East) up to 42%, Zone 4 (North) up to 35%, Zone 5 (North) up to 23%, this because of the pneumatic shading with ETFE modular cushions prevent heat capacity, sun exposer, glare in the workspace.

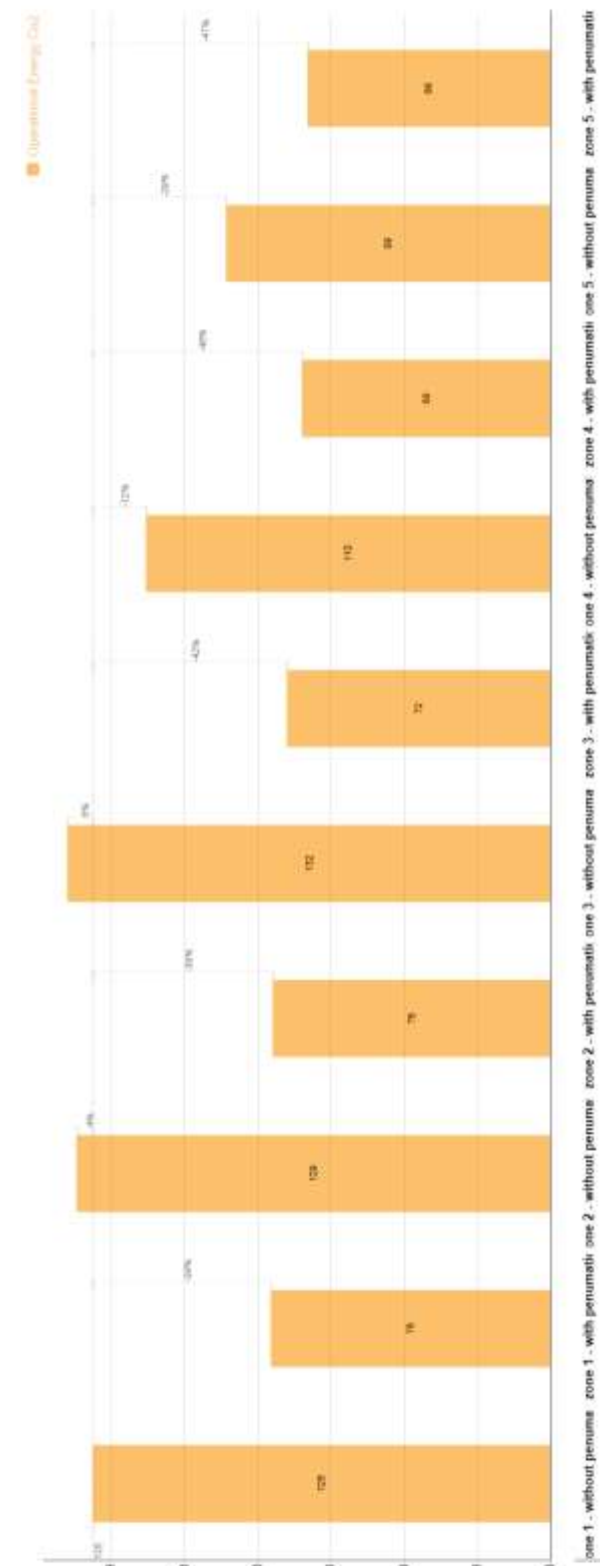
The heating factor otherwise in the winter season increase because the ETFE material works as a shield cover that reduces the temperature in the workspace.

The lighting factor increased in 5 zones by about 30% because the ETFE cushions layer with Argon gas makes the distribution of natural lighting in the work plan reach the deepest point in the floor covered with natural lighting and this makes the low depends on the artificial lighting in the workspace.

The cost factor decreases in the 5 zones by about 45% because of the saving energy use (cooling – heating – lighting) throw the working hours by using pneumatic modular ETFE cushions.







6. Conclusion

Consequently, from the theoretical and analytical case study of applying the ETFE pneumatic modular system on the (DAR AL-Handasah) building facade, some points were concluded followed by some recommendations.

The present analyses study determined the effect of the pneumatic fascade results on daylighting and saving energy, results have shown that;

1- The material ETFE is effective in the worst case of high solar radiation on the 21st of June and reduces the glare by 40% and penetrates the lighting at 30% depth.
2- The pneumatic system makes the fascade adaptable by sensors on the outer screen and this allows the building to contact the environment.
3- Parametric design has great potential to generate different opportunities for solutions in the fascade to reach the optimum design enhancing daylighting and reducing energy consumption.
4- The low cost of using ETFE material in the fascade makes the design easy and durable to construct.

7. Recommendations and future work

1- Make more tests in a different material than ETFE and compare with us.
2- Architecture students must apply the pneumatic modular system in their advanced environmental projects to raise their ability in the new system and have a great role in increasing their creativity, abilities, and skills.

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